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AN INVESTIGATION OF TRANSCRANIAL STIMULATION OF SUPRA-LIMINAL SPEECH STIMULI IN MIXED HEARING LOSS

by

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Introduction to the Problem

Statement of the Problem

The purpose of the present study was:

1. To study the effects of cross-lateralized bone-conducted sounds on speech discrimination test scores of subjects with mixed hearing loss.

2. To investigate methods of improving control over contralateral participation, if it does occur, through appropriate masking procedures.

Significance of the Problem

Determination of monaural speech discrimination scores is an integral part of much research and clinical work in audiology. These measurements are usually made with phonetically balanced words, or some other test of speech discrimination and are delivered at a level that is comfortable in loudness for the subject. The resultant speech discrimination scores have a strong influence on a number of clinical decisions. Among these are:

the election of corrective middle ear surgery, and the appropriate ear to operate first; indications for the possible benefits of a hearing aid and the appropriate ear to select for fitting; the presence of serious medical conditions such as endolymphatic hydrops and acoustic neurinoma.

The literature is replete with procedures for eliminating the non-test ear in threshold auditory tests; however, little mention has been made of contralateral ear participation in supra-threshold tests, such as speech discrimination. The participation in a speech discrimination test by the opposite ear occurs when a significant difference (exceeding the interaural attenuation) exists between ears for auditory thresholds for pure tones or speech reception thresholds. In such cases the signal may cross-lateralize either around the head by air-conduction or across the skull via bone-conduction from the poorer to the better ear. Masking is necessary to eliminate better ear participation in such cases.

Contralateral ear participation in speech discrimination tests is more obscure when small differences exist between auditory thresholds in each ear. In a previous study the present writer has found[1] that, depending on the intensity of the speech signal and the interaural difference for threshold, the better ear augments the poorer ear in speech discrimination in cases of slightly asymetrical sensori-neural hearing loss.

The writer is unaware of any work reported in the literature in which a study was done to determine the degree to which there is a contribution by bone-conduction to the speech discrimination ability of the opposite ear in conductive or mixed hearing losses. If the speech discrimination score based on a signal introduced by air-conduction into one ear is augmented by the simultaneous bone-conduction reception of the signal in the opposite ear, the resulting scores will be inaccurate. Masking should be used to offset the possibility of cross-lateralization when it may exist.

Definition of Terms

Air-bone gap. "The difference in decibels between the hearing level for a particular frequency as determined by air conduction and bone conduction."[2]

Auditory nervous system. "The auditory nervous system is that portion of the central nervous system (CNS) which carries impulses from the cochlear end organs to the auditory cortex."[3]

Binaural. "Binaural listening is listening with two ears."[4]

Contralateral. Occurring on the opposite side. In the present study the term was used to refer to a sound introduced into one ear and heard in the opposite ear.

Cross-lateralization. "Cross hearing takes place when sounds delivered to one ear transmit energy either around or through the head in sufficient quantity to stimulate the opposite ear."[5]

Dichotic. Conveyance of one sound to one ear and another sound to the opposite ear at the same instant.

Effective masking for speech. As used elsewhere by the present writer to mean the minimum amount of white noise required to shift the threshold of a speech sound by two decibels.[6]

Frequency-response characteristic. "The response of a device or system is a quantitative expression of the output as a function of the input under conditions which must be explicitly stated. The response characteristic, often presented graphically, gives the response as a function of some independent variable such as frequency or direction."[7]

Insert receiver. An air-conduction receiver inserted into the external auditory meatus by means of a rubber insert tube.[8] For the present study a Beyer phone, Model DT 509 was used.

Interaural attenuation. The reduction in intensity of a sound (in decibels) as it travels from one ear to the other.

Low-pass filter. "A low-pass filter is a wave filter having a single transmission band extending from zero frequency up to some critical or cutoff frequency, not infinite."[9]

Masking. "Masking is the amount by which the threshold of audibility of a sound is raised by the presence of another (masking) sound. The unit customarily used is the decibel."[10]

Method of limits. "The method of limits is one of three classic psychophysical procedures for measuring the differential or absolute threshold.

In the method of limits the experimenter gradually increases or decreases either a stimulus dimension or a difference between two stimuli and notes the change in the observer's response (e.g., from audibility to inaudibility, or vice versa)."[11] In the present instance the method was used to obtain measurements of an absolute threshold.

Mixed hearing loss. "A combination of conductive with sensory-neural hearing loss. This term is restricted by custom to peripheral hearing losses."[12]

Monaural. "Monaural listening is listening with one ear."[13]

Phonetically balanced list. "A PB list is a list of monosyllabic words that contains a distribution of speech sounds that approximates the distribution of the same sounds as they occur in conversational American English."[14]

Sensation level (SL). "The level above threshold of a sound is the pressure level of the sound in decibels above its threshold of audibility for the individual observer."[15]

Sensori-neural hearing loss. "A hearing impairment due to abnormality of the sense organ, the auditory nerve, or both. Some or all hearing levels by bone conduction are abnormal, but the air-bone gaps are small or absent."[16]

Speech discrimination test. "A hearing test used to determine the subject's ability to hear and to repeat correctly the American English speech sounds represented in PB word lists."[17]

Standard audiometer earphone or receiver. A supra-aural air-conduction receiver. For the present study the receivers used were TDH-39's mounted in MX/41-AR cushions.

Supraliminal. "Above the threshold of sensation or above the threshold of difference."[18]

VU (volume units) meter. A VU meter is used to monitor the input from a microphone prior to amplification. For the present study the meter was used to monitor the input of a tape recorder.

Basic Assumptions

It is possible that, unless appropriate measures are taken, cases with mixed hearing loss may have their monaural speech discrimination scores confounded in several ways:

1. The discrimination score of the poorer ear may be raised by the contribution of the better ear.

2. The speech discrimination scores of both ears may be raised beyond their true level by binaural rather than monaural reception of speech stimuli.

3. Minimum levels of effective masking may produce overmasking. This would result in a shift in the auditory threshold, thereby lowering the sensation level of the signal resulting in a lower discrimination score in the test ear.

While these difficulties may exist in cases of pure conductive hearing loss, they were not considered significant since it is generally accepted that speech discrimination is normal in such cases.

If no masking is used in discrimination tests, and contralateral participation is occurring, the subject would be unaware of the contribution of the weaker signal due to the Stenger effect[19] since two signals of the same frequency, when introduced simultaneously into both ears, results subjectively, in only the louder signal being heard. The work of Bocca[20] indicates that a loud distorted signal in one ear presented simultaneously with a soft but undistorted signal in the other ear results, in subjects with normal auditory nervous systems, in a fusion of signals that yields better discrimination than would be obtained by either ear alone.

Basically what may be taking place in some mixed hearing losses is that the intensity of the stimulus words may exceed the amount of energy required to set the skull into vibration in sympathy with the complex vibrations of the air-conduction receiver. If the intensity level of the signal received by bone-conduction is in excess of the subject's bone-conduction hearing level, the signal could be heard by bone-conduction as well as air-conduction. Since there is little or no interaural attenuation for bone-conducted stimuli[21] the speech signal might be heard by bone-conduction in the contralateral as well as the ipsilateral ear.

In the theoretical case cited above masking would obviously be required to eliminate the contralateral ear from test participation. The next step would be to compute a level of masking which would be effective. If the masking source is carefully calibrated, the least amount of effective masking would have to be equal to the presentation level of the speech signal in the test ear, minus 40 decibels for interaural attenuation (this is a conservatively low figure) plus the air-bone gap in the masked ear to offset the attenuation of the masking noise produced by the conductive component of the hearing loss.

In some cases the minimum amount of masking described above would be high enough in intensity to cross-lateralize to the test ear creating problems of overmasking. The present writer has stated elsewhere[22] that, "It must be borne in mind that the danger of over-masking exists whenever the level of EM (effective masking) minus the IA (interaural attenuation) of the noise exceeds the BC (bone-conduction) threshold in the test ear." In some cases therefore, minimum masking would be overmasking, and in other cases of severe loss maximum masking would be ineffective, resulting in the former case in discrimination scores being lower than the true discrimination ability of the ear and in the latter case in the discrimination score being higher than the true discrimination in that ear.

Basic Hypotheses

The several problems involved in determination of monaural discrimination scores in cases of mixed hearing loss were examined by testing the following null hypotheses:

1. Contralateral participation in discrimination tests by bone-conduction in mixed hearing loss does not have an effect on monaural speech discrimination scores when the air-conduction audiograms are symetrical.

2. Contralateral masking with standard audiometer earphones produces no significant change in speech discrimination when the speech signal is delivered through standard earphones.

3. There is no significant difference between the speech discrimination scores obtained when speech stimuli and masking are presented via insert earphones and the speech discrimination scores obtained when speech stimuli and masking are presented via standard earphones.

Delimitations of the Study

1. The number of subjects used in this study totaled 46. Twelve subjects had normal hearing in both ears, 20 had bilaterally symetrical sensori-neural hearing losses, 12 had bilaterally symetrical mixed hearing losses, one had normal hearing in one ear and a total sensori-neural hearing loss in the other ear, and one had a mixed hearing loss in one ear and a total sensori-neural loss in the other.

2. No subject had active ear disease at the time of testing.

3. All subjects could follow instructions readily and performed the tasks easily after a period of practice.

Significance of the Study

Some subjects with mixed losses of hearing may exhibit monaural speech discrimination scores which are raised by participation of the opposite ear hearing the signal by bone-conduction. Normal methods of masking through standard audiometer earphones may produce overmasking by generating a bone-conducted masking noise in the test ear, resulting in speech discrimination scores appearing lower than the true discrimination ability of the ear. This may mean that performance on discrimination tests may lead to inaccurate scores. Delivering masking and speech discrimination materials through insert receivers may serve to isolate the test from the masked ear during speech discrimination testing. In such cases the discrimination score would reflect the true discrimination ability of that ear.

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CHAPTER II

REVIEW OF THE LITERATURE

In reviewing the literature for the present research, several separate areas had to be considered and their interrelationship brought together in order to understand the problems which may be met in the isolation of one ear for the purpose of speech discrimination testing. These areas include: speech audiometry cross-lateralization, bone-conduction for speech, binaural hearing and masking.

Speech Audiometry

Harris[23] has stated that:

> The need for speech audiometry arises because speech is by far the most important class of sounds we wish to hear. Pure-tone audiometry often gives an erroneous or even misleading notion as to how an individual can handle speech communication.

For some time the use of phonetically balanced words has been a method for ascertaining speech discrimination ability.[24,25] Hirsh[26] discussed the use of speech audiometry for determining hearing level and discrimination ability. He stated that the procedure does not provide a basis for making decisions about specific lesions, that it is not general enough to infer information about every day hearing ability of the listener, but has application in evaluation of hearing for social and medicolegal purposes.

Four methods may be used in presenting speech discrimination materials. They are: commercially available tape recordings, disc recordings, tape recordings of the aforementioned pressings, or monitored live voice using a microphone. In each case a carrier phrase is customarily used such as "You will say ____" or "Say the word ____." The last word of the carrier phrase is brought up to zero decibels on the VU meter of the audiometer so that the test word itself is said with normal effort.[27]

The subject usually replies orally to speech discrimination tests by repeating the word he thinks he has heard. Creston et al[28] compared the reliability of taped and live voice speech tests. They found the results to be equal but that live voice gave more "flexibility."

Merrell and Atkinson[29] found that significant differences occurred between written and oral responses of subjects. Listeners erred in the direction of scoring wrong responses as correct.

Carhart[30] discussed at length some of the variables imposed on speech discrimination tests such as recording technique, equipment used and sensation level, as well as the different results obtained with different materials. He stated that the important thing to try to get on a discrimination test is the highest possible PB score and the only way an examiner can know this has been obtained if testing is performed at one level is to get close to 100% correct. DiCarlo and Brown[31] found the most comfortable listening level and the highest obtainable discrimination score for PB words to be 31.94 decibels above the speech reception threshold for subjects with mixed hearing loss and 28.52 decibels above the speech reception threshold for subjects with sensori-neural hearing loss.

Most speech discrimination tests have been performed either through standard audiometer earphones, or through a loudspeaker in a sound field. Tillman et al[32] sought to establish the difference between earphone and sound field measures of threshold sound pressure level for spondee words. They delivered recorded spondee words to standard and insert earphones and to a loudspeaker. Monaural spondee threshold sound pressure levels were established on normal and hard of hearing listeners. For both groups the mean sound field threshold sound pressure level was 7.5 decibels lower than conventional earphones and 12.5 decibels lower than insert phones. This paper was relevant to the present research in that it indicated that speech materials can be delivered with no difficulty from an audiometer via insert receivers, although the normal zero decibel reference for speech might be five decibels higher than for standard audiometer earphones.

Cross-lateralization

A usual explanation for one ear hearing a sound introduced via an earphone to the other ear is that the sound may be increased in intensity to the point where the signal escapes from under the earphone into the air. After some degree of attenuation, the signal is heard by the opposite ear by getting underneath that earphone and entering the external auditory meatus.

Hood[33] has shown that cross-lateralization of air-conducted stimuli takes place because of mechanical vibration of the skull, and that insert receivers could increase the interaural attenuation up to 90 decibels because they vibrate a smaller area of the skull.

In discussing cross-lateralization Langenbeck[34] stated:

> It must be remembered that the shadow curves . . . always apply to the bone conduction of the better ear. For bone-conduction measurements this is obvious from the outset. But even when measuring air conduction, reference must be made to the bone conduction of the better ear.

The acoustic attenuation between the ears for pure tones has been described by Zwislocki.[35] The results of his experimental findings may be seen in Table 1.

TABLE 1

INTERAURAL ATTENUATION FOR PURE TONES

Frequency	125	250	500	1000	2000	4000	8000
Decibels	40	40	50	55	60	65	70

It can be seen from Table 1 that low frequencies cross-lateralize with less attenuation than high frequencies. If cross-lateralization occurs by air-conduction this may be explained on the basis of the fact that higher frequencies do not bend as low frequencies do and therefore do not circle the head as readily.

Konig[36] compared insert earphones to midget earphones with short lengths of plastic tubing and found less interaural attenuation for the insert phones. He concluded that the general application in audiometry of hearing aid receivers is premature since they fall off so sharply in their frequency response in the high frequencies. He stated that hearing aid receivers may be used if regular phones cannot be used with certainty.

Feldman[37] compared the interaural attenuation characteristics of standard versus insert earphones on unilaterally deafened ears. He found a minimum of 20 decibels greater interaural attenuation provided with insert earphones. He stated that:

> . . . except in rare cases, transmission of sound through the middle ear at or beyond 50-60 db levels apparently proceeds from eardrum via the air in the middle ear to round-window and is independent of the area of the earphone in contact with the skull.

The above statement is contradictory to the findings of Studebaker[38] who recommended the use of insert earphones for masking because an earphone designed to reduce the area of the head exposed to a masking noise increases the interaural attenuation.

Langenbeck[39] stated that insert receivers offer 70 to 80 decibels of interaural attenuation. His explanation for the increased amount of sound isolation is:

> For stimulation of bone conduction the decisive factor is the total sound energy radiating on to the head, but for the threshold of hearing only that part of it which reaches the tympanic membrane through the auditory meatus. Thus bone-conduction stimulation must occur the earlier, in

> relation to the threshold of hearing of a normal ear, the larger the area of the head struck by the sound from the receiver.

Littler and Knight[40] reported that with a bone-conduction vibrator applied to one mastoid process there is very little difference in level in the opposite ear from 250 through 2000 Hertz. They also showed that the interaural attenuation for standard receivers is 45 to 50 decibels, and for insert receivers 75 to 80 decibels. They suggested that insert phones be used for masking in bone-conduction testing.

The data of Palva and Palva[41] indicated that insert receivers increased the interaural attenuation by 15 to 20 decibels and facilitated bone-conduction audiometry. DeBoer[42] claimed that earphones of the hearing aid type increase the interaural attenuation up to 80 to 90 decibels in normal subjects.

Hood[43] demonstrated that a bone-conducted sound introduced anywhere on the head was heard with equal loudness in both ears. He recommended insert receivers for masking which he stated would give 80 to 90 decibels of interaural attenuation.

Palfalvi and Surjan[44] used 12 cases of total unilateral loss to measure cross-lateralization for bone-conducted speech stimuli. The differences between speech reception thresholds measured from the mastoid process of the normal and abnormal ear varied from seven to 12 decibels with an average of 10 decibels. Speech discrimination was unaffected when measured from the contralateral mastoid. This last finding is in some disagreement with Kodman[45] who found some intelligibility to be lost across the skull. This he attributed to the greater attenuation of the high frequency consonants, although he was using air- rather than bone-conduction receivers.

It is not known with certainty at this time whether the route a sound follows in getting from one ear to the other is primarily air- or bone-conduction. Similarly it is not known why insert earphones provide more interaural attenuation than standard earphones. Several facts do, however, seem to emerge. The greater the intensity of the signal delivered to one ear, the greater the likelihood that the other ear will hear the signal. In an attempt to isolate one ear from the other, there is a body of present evidence to indicate that there is greater interaural attenuation for insert earphones than standard earphones.

Bone-Conduction for Speech

Goetzinger and Proud[46] introduced speech stimuli to a bone-conduction vibrator via a speech audiometer. After initial determination of a zero reference level for speech via bone-conduction they found no significant differences between the bone-conducted speech reception thresholds and the pure tone bone-conduction averages at 500, 1000 and 2000 Hertz. Speech discrimination scores were found by these authors to be normal for bone-conducted stimuli at 25 decibels sensation level.

Hahlbrock[47] used bone-conduction speech audiometry to separate auditory from tactile bone-conduction responses. Martin and Wittich[48] found that many deaf children were unsure of whether the sensations they received from bone-conduction were auditory or tactile. Walczak[49] found bone-conduction speech audiometry to be highly reliable and valid on 74 subjects with different kinds of auditory defects.

It can be concluded from the literature cited above that speech can be delivered by bone-conduction with a minimum of distortion. This is relevant to the present research since this may be precisely what happens in the case of a subject hearing speech discrimination materials by bone-conduction in one ear while they are delivered by air-conduction to the opposite ear.

Binaural Hearing

Shaw et al[50] showed that when both ears were stimulated above threshold, subjective loudness was greater than to either ear alone. They also found that the absolute threshold for pure tones was lower when both ears were stimulated. They concluded that binaural presentation of auditory stimuli resulted in a fusion of signals and a lowering of threshold by one to two decibels. The binaural threshold of detection for speech was found to be the same as for pure tones. When the two ears were presented with speech which was heard at the same sensation level in each ear, the binaural threshold was approximately three decibels lower than for either ear alone. Groen and Hellema[51] concluded from their research that the binaural speech reception threshold was six decibels lower than the monaural speech reception threshold.

Azzi[52] found that binaural summation is at its maximum when auditory stimuli reaching the two ears are of the same frequency. He concluded that binaural fusion takes place when sounds of physically equal characteristics reaching the two ears separately give a single image in the center of the head.

Bocca[53] tested binaural hearing function by delivering speech stimuli through two channels. Channel 1 provided attenuation which was linear with respect to frequency. Channel 2 provided attenuation of the same signal plus low-pass filtering with the roll-off beginning at 500 Hertz. He did not specify the rejection rate of his filters. Channel 1 was directed to one earphone and adjusted to a sound pressure level just high enough to permit no more than 40% discrimination. Channel 2 was set for a sensation level of 45 decibels, which provided a discrimination score of about 50%. Discrimination scores were not significantly higher when both channels terminated in a single ear. When each channel led to a different ear of a subject with normal hearing, discrimination scores were significantly higher.

Bocca's experiment shows evidence of binaural summation and integration at the level of the central nervous system since the binaural improvement could not be demonstrated on subjects with known brain stem lesions. Jerger[54] discussed three cases and used a combination of Bocca's approach using PB words, and loudness balancing of pure tones, with results similar to Bocca's.

The research of Bocca and Jerger would seem to support the belief that, in the presence of a normal auditory nervous system, binaural fusion occurs, so that an undistorted speech signal of low sensation level in one ear has the effect of increasing the speech discrimination of a comfortably loud but distorted signal in the opposite ear. The low level signal could be very low since the addition of a supra-liminal speech signal in one ear makes a previously sub-liminal signal in the other ear audible, as found by Hirsh.[55]

Hughes[56] has stated that the outputs of the two cochleae to the central mechanism are summed in their power and the binaural threshold is therefore lower than the monaural threshold by two to three decibels for low frequencies. He found, however, that the binaural threshold for the high frequencies was six to eight decibels lower than the monaural thresholds. This appears not to be a summation of power, but due to some other effect.

Hughes' findings are related to the present research in that they may have an effect on the perception of a speech signal which has cross-lateralized from the opposite ear. Since low frequencies have less interaural attenuation than high frequencies,[57] frequency distortion of the speech signal would be produced in the form of low-pass filtering to the non-test ear. The high frequency deficit might be compensated for by the additional intensity provided to the high frequencies by binaural fusion. In other words, the high frequency components of the speech signal attenuated by cross-lateralization would be restored by binaural fusion.

The binaural speech reception threshold is lower than the monaural threshold of the better ear, although different researchers have given different values. Keys[58] found 4.14 decibels and Shaw et al[59] three decibels of improvement in binaural over monaural thresholds.

Causse and Chavasse[60] have shown that,

> . . . the physical difference between two sounds, one monaural, the other binaural, should be three decibels at threshold, but this difference reaches six decibels when the sensation level rises to around 35 decibels and above.

Harris[61] compared hearing in the monotic, diotic and dichotic states. He used a V-cord and double V-cord arrangement and found, among other things, that there is a principle of redundancy and that dichotic presentation of speech increases intelligibility over monotic or diotic presentations. It seems to the present writer that this may be what happens when a weak signal is heard by cross-lateralization while testing discrimination in the poorer ear. Support for this supposition may be gleaned from the word of Hayashi et al[62] who found that subjects with cochlear hearing loss showed good binaural fusion.

Based on his observations, Bergman[63] has stated that,

> . . . binaural hearing does occur in persons with ears which are markedly different from each other, provided the sound is above the audibility threshold of the poorer ear.

The phenomenon of binaural hearing, with its various ramifications, is directly related to the present research. It is known that thresholds are lowered by binaural presentation of accustic stimuli, that speech discrimination is improved by dichotic presentation, and that the loudness function is steeper when the stimuli are binaural than when they are monaural. All of these phenomena are based on research performed by directing acoustic signals directly into one or both ears via earphones. What is unique to the present research is an attempt to discover whether the same phenomena take place when the speech signal is directed only to one ear and heard simultaneously in the other ear via cross-lateralization.

Masking

At the present time, the introduction of a masking signal to one ear is the only method known to eliminate hearing by cross-lateralization of a supra-liminal signal.

On the subject of masking, Newby[64] has stated that,

> While the indications for the use of masking during threshold determination are fairly clear, it may not always be apparent that masking should be employed while testing the patient's discrimination. If there is sufficient difference in acuity between the ears to justify the use of masking while obtaining the SRT, then of course masking should be utilized in the discrimination test of the poorer ear. There are occasions, however, when threshold differences between the ears are not sufficient to require masking while measuring SRT, and yet masking is required to prevent the participation of the better ear in discrimination testing.

On the subject of masking for speech discrimination, Hardy[65] declared that,

> The ear with sensorineural involvement may perform with reasonable equivalence at minimal levels, but typically shows

> the effect of distortion for discrimination, the more so in noise. As a part of a clinical battery of tests, speech audiometry offers very useful data in differential diagnosis and, moreover, is fully amenable to the use of masking for the differentiation of single ear performance.
>
> Most reports of differential tests for the determination of otosclerosis include a hackneyed phrase - "adequate masking was employed." There would be less begging of the question of masking, and more general information, if we could know what kind of masking, how much, how presented, and how evaluated. This kind of reporting would really advance our knowledge of these troublesome relationships, and teach us all more about them.

In their brief discussion of masking for testing the speech reception threshold, O'Neill and Oyer[66] stated that,

> If there is a difference of 30 decibels between the average loss for each of the ears, white-noise masking is introduced into the better ear. The masking level is set at a level 20 db above the better ear average loss.

In discussing speech discrimination testing these authors wrote,

> A similar procedure is followed for the opposite ear. If there is a disparity of 30 db between the three-frequency average for the better and worse ear, masking is introduced in the manner indicated for speech-reception testing.[67]

Examination of the above statements reveals that no mention was made of the level of the noise required for discrimination testing and the reader is permitted to assume that a masking level high enough to avoid opposite ear participation for speech reception testing will be sufficient for discrimination. This appears to be a tenuous assumption indeed.

Harris[68] discussed the use of masking in speech audiometry with only the following reference,

> The purpose of this test is to assess speech reception in an ear defective by air conduction to the extent of 40 dB or more (mean loss at 500, 1000 and 2000 c/s) with respect to the better ear. SRT and discrimination score (DS) are computed as usual, except that a masking noise of the order of 40 dB is inserted in the better ear.

Newby[69] cited the case of a patient with only a 22 decibel difference in speech reception thresholds but up to a 55 decibel difference in thresholds for the higher frequencies. Masking was required for the higher frequencies in order to avoid cross-lateralization. Since the discrimination test was done at 40 decibels sensation level, a score of 88% was obtained without masking and 70% with masking, indicating that the better ear was assisting in discrimination. In his previous text, Newby's[70] only reference to masking for the speech reception threshold was, "From the pure-tone test which you have already administered, you will know whether masking will be necessary in either ear for the speech tests."

Goetzinger et al[71] stated that there is a great need for masking when the non-test ear is conductively deafened. They claimed that the problem is greater for speech discrimination testing and other supra-liminal tests than for threshold measurements. This is a logical statement, however, no data were presented to support it.

Jerger and Tillman[72] developed the sensori-neural acuity level (SAL) test as an alternative to traditional bone-conduction as a measurement of cochlear reserve. With this technique a bone-conducted noise is introduced to the forehead producing a shift in threshold for air-conducted pure tones. The subject's threshold shift is subtracted from a previously established normal threshold shift and the difference in decibels is the sensori-neural acuity level for that frequency in that ear. This procedure was modified by Bailey and Martin[73] who substituted spondee words for pure tones. These procedures demonstrate that a bone-conducted noise of high intensity shifts the threshold for air-conducted signals, either pure tones or speech.

The data cited above would seem to support the reasoning that a high intensity level of masking delivered by an air-conduction receiver to one ear could, by cross-lateralization have a masking effect on the bone-conduction of the opposite ear. The air-conduction threshold for either speech or pure tones would then be shifted. In the case of a discrimination test, this shifting upward in threshold results in a lowering of the sensation level of the speech materials presented to that ear. In such a case, the signal would continue to be heard, but would be at a lower sensation level, possibly resulting in a lower discrimination score.

In the words of Langenbeck,[74]

> To decide whether and how much masking should be used, three things must be known. (1) The threshold curve of the better ear, so that in principle the better ear must be tested first. (2) The shadow curve. (3) The properties of the masking noise.

On the subject of overmasking, Langenbeck[75] said,

> Noises of any intensity cannot be used at will for masking the better ear, because the noise from the masking receiver will be heard by shadow hearing in the other ear in exactly the same way as air-conducted tones. If too loud a noise be chosen, then the ear under test may possibly be masked as well.

Ehmer[76] and Rittmanic[77] showed that a masking noise has the effect of masking frequencies which are higher than those included in the spectrum of the masking noise. It seems obvious that the low frequency components of a broad band noise used to mask one ear during a speech discrimination test might therefore lateralize more readily to the test ear than the high frequencies but still have the effect of some high frequency masking. This masking could affect the consonant sounds and result in a lower discrimination score than the subject would otherwise give.

Wegel and Lane[78] coined the term "central masking" to mean the effect on the threshold of a tone in one ear produced by a noise in the opposite ear, where the intensity of the noise was not sufficient to produce peripheral masking by cross-lateralization. Martin et al[79] showed that a central masking effect existed for cold running speech that varied from two to eight decibels in subjects with normal hearing. The present writer repeated this study using spondee words[80] and found the modal central masking effect for spondee words to be five decibels.

The present writer found experimentally[81] that a masking noise delivered to one ear had no effect on discrimination scores in subjects with sensori-neural hearing loss, so long as the central masking effect was compensated for and overmasking was avoided. He also found that, in symetrical sensori-neural hearing loss, if the speech signal in the poorer ear was of sufficient intensity to cross-lateralize to the better ear, discrimination scores were significantly higher without masking than with masking. The conclusion was drawn that it was indeed the participation of the better ear that was responsible for the increase in discrimination scores.

Based on the above findings, careful calibration of effective masking for speech was recommended and the following formula was suggested for masking during speech discrimination testing: PBHL-IA=EM, that is, the level of the PB words presented to the poorer ear minus an interaural attenuation of 40 decibels equals the level of effective masking for the better ear. This level of masking would appear appropriate if the better ear was normal or with a sensori-neural hearing loss, however, it would seem to be insufficient if the masked ear had a conductive or mixed hearing loss, since the conductive component would attenuate the intensity of the masking noise before it reached the cochlea. To compensate for the conductive component, it would seem that the level of the effective masking would have to be increased by the amount of the air-bone gap in the masked ear.

Masking, although a routine audiometric procedure is more complicated in supra-liminal tests, such as speech discrimination, than for threshold measurements like pure tones or speech reception thresholds. The danger of overmasking occurs when the level of the noise in the masked ear, minus the interaural attenuation for the noise is in excess of the bone-conduction threshold of the test ear. This results in a shift of threshold for the test ear and a lowering of the sensation level of any supra-liminal stimulus presented to that ear.

A masking effect exists for speech stimuli which has been attributed to central masking. This occurs when noise is presented to the ear contralateral to the one receiving the speech signal and results in a shift in threshold for the speech which is directly related to the level of the noise. Determination of the need for and careful calibration and presentation of the masking noise is therefore necessary in speech discrimination testing.

Summary

The speech signal in a discrimination test is delivered at a supra-liminal level. The danger of opposite ear participation in the test is therefore greater than for threshold tests. Cross-lateralization of acoustic stimuli is directly related to the intensity of the speech signal, the interaural attenuation of the subject, and the bone-conduction thresholds of the ear contralateral to the one receiving the speech stimuli. The danger of cross-lateralization of speech occurs when its presentation level, minus the subject's interaural attenuation is in excess of the bone-conduction thresholds in the opposite ear.

If a speech signal is heard via bone-conduction in the non-test ear during monaural discrimination testing, it may not be perceived as audible due to the Stenger effect. However, through binaural fusion, or due to the assistance of a cochlea introducing less distortion than in the test ear, the discrimination score may be raised. Fidelity of the bone-conducted speech signal may be preserved since bone-conduction is an efficient means of transmitting speech stimuli. If a signal is presented to both cochleae and the subject has a normal auditory nervous system, the discrimination scores may be raised by binaural fusion and the scores will inaccurately represent monaural discrimination.

The use of insert type receivers has been demonstrated to be effective in increasing the interaural attenuation for the masking stimulus. Therefore, these receivers may be used to avoid overmasking in speech discrimination testing. To further isolate the two ears the speech stimuli may also be presented via insert receivers.

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CHAPTER III

PROCEDURE

Since the present project was designed to investigate the use of insert earphones for purposes of delivering a masking noise and speech materials, a number of facts had to be learned about these earphones. To investigate these various factors, five experiments were designed, each one with the purpose of determining a separate factor. Experiment I was designed to find the zero reference level of speech for insert phones, which was compared to standard earphones. Experiment II was designed to find the zero reference level of effective masking for speech using insert and standard earphones as output transducers. Experiment III compared speech discrimination scores obtained through insert phones with speech discrimination scores obtained through standard phones. Experiment IV was designed to determine the effect on speech discrimination scores of cross-lateralization of speech discrimination stimuli. Finally, Experiment V was set up so that speech discrimination scores of subjects with mixed hearing loss could be compared when the data were collected through standard phones, with and without contralateral masking, and through insert phones with contralateral masking.

Equipment. All data were obtained in a prefabricated, commercially available, two-room test suite. The subject's area was a room-within-a-room arrangement, the inside dimensions of which were 12 feet by 12 feet by eight feet high. Acoustic isolation within the frequency range 500 to 8000 Hertz was within required limits and was checked by octave band analysis using a Bruel and Kjaer sound level meter, Type 2203, with octave band filter set Type 1613. Since sound pressure levels are not published giving the minimum requirements for audiometric testing on the ISO-1964 scale, some adjustive computations had to be made. The maximum permissible ambient noise level for air-conduction testing on the ASA-1951 scale[82] is shown in Appendix A. The differences between the ASA-1951 and ISO-1964 standards[83] were subtracted from these levels at each test frequency. The resulting figures are the maximum allowable sound pressure levels for air-conduction testing on the ISO-1964 scale. The results of the sound analysis performed in the subject's room and their comparison to the minimum requirements for air-conduction testing may be seen in Appendix A.

All audiometric data were obtained with an Allison Model 22 Diagnostic/Research Audiometer terminating in a matched pair of TDH-39 receivers mounted in MX/41-AR cushions. The audiometer was checked monthly to be certain that calibration for air-conducted pure tones on the ISO-1964 scale was maintained. These audiometer checks were conducted on a Bruel and Kjaer artificial ear, Type 4152, in conjunction with a Bruel and Kjaer sound level meter Type 2203 and octave filter set Type 1613.

Calibration for speech was done on the same units described above by playing a tape recording of a 1000 Hertz tone, copied from a disc recording of CID Auditory Test W-22, List 2A through the speech circuit. The gain control on the VU meter was adjusted to zero and the hearing level dial was set to 70 decibels so that the sound pressure level on the artificial ear read 90 decibels. In order to check for peak readings of the stimulus words, a tape recording of CID Auditory Test W-22, List 2A was played through the speech circuit of the Allison Audiometer. The present writer and an independent observer watched the peak readings of each of the 50 PB words on the meter and recorded them on separate scoring sheets. A comparison of the two separate impressions of the peak readings of the words agreed plus/minus 0.5 decibels. The peak intensity of the words ranged from zero decibels to plus 2.5 decibels of the 90 decibel sound pressure level reading and averaged plus 1.2 decibels.

Calibration of the bone-conduction oscillator Model B-70A was accomplished on the foreheads of a group of reliable subjects with mild sensorineural hearing losses following the procedure of Roach and Carhart.[84]

The selection of subjects was made as follows: Thresholds of air- and bone-conducted pure tones were measured using the method described by Carhart and Jerger.[85] When necessary, masked thresholds for pure tones were measured using the procedure recommended by the present writer.[86] The masking noise was supplied by a Beltone narrow-band noise generator, Model NB 102.

All speech stimuli were played on a Viking tape deck, Model 87 connected to the Allison Audiometer. Tape speed was always 7.5 inches per second. Speech stimuli were copied on magnetic tape from previously unplayed disc recordings, fed from a Garrard record player to the Viking tape deck. Spondee word lists were copied from CID Auditory Test W-1 and phonetically balanced word lists from CID Auditory Test W-22, both obtained from Technisonic Studios.[87]

The method used to measure speech reception thresholds was that described by Chaiklin and Ventry[88] using two decibel steps in measurement. Speech stimuli used to measure speech discrimination were presented at 30 decibels above the speech reception threshold of each subject. This level was selected based on the findings of DiCarlo and Brown.[89]

The insert earphones used in the experiments were a matched pair of Beyer phones, Model DT-509. These earphones were used with a selection of different sized rubber ear tips. The ear tips were cleaned after each use in a solution of zephrine chloride. The fit of the insert earphones was always tight and was further assured by a firm plastic band which exerted pressure on both sides of the head. Although the insert earphones were certified by the manufacturer to be closely matched in frequency response, it was considered best to use one phone only for speech stimuli and the other for masking. The insert earphones were connected to the audiometer circuit by unplugging the standard headsets in the subject's room and replacing them with the phone plugs from the insert earphones.

Experiment I

Experiment I was an initial step in determining a zero reference level in decibels for the use of insert phones for testing speech reception thresholds.

Subjects. The twelve college students who were selected for this phase of the study had negative otological histories. Their ages ranged from 18 to 24 years with a mean age of 20.5 years. Two subjects were male and 10 female. All subjects had normal hearing in both ears, which was defined as no hearing threshold level higher than 10 decibels on the ISO-1964 scale at octave points between 250 and 8000 Hertz. All subjects were given ample time in practice sessions so that they were familiar with the test procedures and could qualify as trained listeners.

Procedure. Each subject was given practice in listening to spondee words through earphones and was permitted to read through a printed list of the test words, which was arranged in alphabetical order. This was done prior to the onset of testing in order to minimize practice and learning effects. Tillman and Jerger[90] found that short term practice with spondee words resulted in slight improvement in threshold, while familiarity with the word lists improved thresholds by five decibels. Speech materials were taken from the tape input of channel 1 of the Allison Audiometer. Adjustment was made to VU zero on channel 1 from the 1000 Hertz calibration tone copied onto the tape from the commercial disc recording.

Calibration for speech reception thresholds was carried out in the following manner: For six subjects, speech reception thresholds were measured with one of the standard earphones and then with the insert earphone designated for speech. With the other six subjects the test order was reversed to minimize order effects.

Collecting the Data. The intensity was varied on the hearing threshold level dial on channel 1 of the Allison Audiometer until a level was found at which three out of six spondee words could be repeated correctly by the subject. The hearing threshold level at which this point occurred was scored on the data collecting sheet prepared for this purpose (see Appendix B).

Treatment of the Data. In order to determine whether there was a significant difference in the stability of speech reception thresholds obtained with spondee words as measured with standard earphones and insert earphones, a *t* test for the significance of the difference between the variances was employed. The method used was that described by Ferguson.[91]

Experiment II

Experiment II was an initial step in determining a zero reference level in decibels for effective masking for speech through standard and insert earphones.

Subjects. The twelve subjects selected for experiment were the same as those used in Experiment I.

Procedure. Each subject had previously had practice in testing for speech reception thresholds for spondee words during Experiment I. Calibration of the input level of the spondee words on the VU meter was carried out on channel 1 of the Allison Audiometer using the 1000 Hertz tone in the same fashion as in Experiment I. The noise used for masking was obtained from the white noise input of channel 2 of the Allison Audiometer. The noise was set to the "normally on" position and the gain control of channel 2 adjusted so that the VU meter read zero.

Spondee words were played into a single earphone at 20 decibels hearing threshold level. A white noise was introduced into the same earphone and raised in intensity in two decibel steps until none of the words could be repeated at 20 decibels but 50% of them could be repeated at 22 decibels hearing threshold level.

Subjects were seated in the sound treated chamber in the same fashion as in Experiment I, at right angles to and three feet from the window connecting the subject's room to the control room. The method of limits was used. This procedure was employed with the standard earphones first in six subjects and the insert earphones first in the other six subjects to minimize order effects.

<u>Collecting the Data</u>. Subjects repeated the words they heard into the talkback microphone of the Allison Audiometer, which terminated in, after suitable amplification, a speaker in the control room. All subjects were instructed to give a response to each stimulus word even if this required guessing.

<u>Treatment of the Data</u>. After 20 decibels of effective masking was determined by taking the median response, 20 decibels was subtracted from this value on the hearing threshold level dial of the Allison Audiometer and this level was referred to as zero decibels of effective masking for speech. To determine whether there was a significant difference in the stability of measurement of 20 decibels of effective masking with white noise as measured with standard and insert earphones, a *t* test for the significance of the differences

between the variances was employed, as in the case of the speech reception thresholds.[92] The raw data for this experiment may be seen in Appendix B.

Experiment III

Experiment III was designed to ascertain the feasibility of measuring speech discrimination for PB words through insert earphones.

Subjects. A group of 20 subjects with sensori-neural hearing loss was selected. Sensori-neural hearing loss was defined, for purposes of the present study as: an average threshold for air-conducted pure tones of not less than 30 decibels hearing threshold level for the frequencies 500, 1000 and 2000 Hertz, a speech reception threshold which was plus or minus four decibels of the average of the frequencies stated above, an air-bone gap not greater than five decibels at any frequency and a speech discrimination score not greater than 86%. While these initial criteria were met by all subjects on initial testing, some subject's discrimination scores improved up to 90% on subsequent testing, but their candidacy for inclusion as subjects in the study was retained. Ten of the subjects were male and 10 female. Their ages ranged from 29 to 76 with a mean age of 53.2 years.

Procedure. In every case subjects stated they felt refreshed before each discrimination test was performed. There was no visible evidence that fatigue was in any way a factor, especially for the older subjects for whom this might have become a problem.

A practice list of PB words was delivered first to the non-test and second to the test ear. The test ear was, in all cases the one with the poorer speech discrimination score on initial testing. A list of words was taken from list 1 of CID auditory test W-22 for the practice sessions. After practice and a short rest period, speech discrimination tests were performed in the test ear. For 10 subjects the measurements were taken first in the standard and second in the insert earphones and for the other 10 subjects this order was reversed. All PB words used for collection of data were selected from list 2, 3 or 4, since Huntington and Ross[93] found list 1 not to be equivalent to the other three for research purposes. The PB word lists used in this study may be seen in Appendix E.

Collecting the data. Subjects were seated at a desk and wrote their responses to the PB words. These written responses were recorded on duplicator forms which were lined and numbered from 1 to 50. A sample scoring sheet may be seen in Appendix F. Subjects were asked to guess whenever possible at words they were unsure of. If the subject could not understand a word at all he was instructed to draw a line through the space reserved for that word. Before subjects were discharged, any difficulties involving handwriting or spelling were clarified.

Treatment of the Data. The raw data on the third experiment may be seen in Appendix B. Each correct word was given a value of 2%. To determine whether a significant difference existed between subjects' speech discrimination scores for PB words when obtained with standard and insert receivers, a test for differences between the two mean discrimination scores was used. The t test suggested by Dixon and Massey[94] for the difference between means of paired observations was utilized.

Experiment IV

Experiment IV was designed to determine the effect on speech discrimination scores as measured with PB words by cross-lateralization when the speech stimuli were introduced via a standard earphone into an ear with no measurable hearing and heard by the opposite ear. These effects were studied, (a) when the better hearing ear had normal hearing, and (b) when the better hearing ear had a mixed hearing loss.

Subjects. A single subject with normal hearing in one ear and no measurable hearing in the other ear was used in the first segment of the problem. She was 49 years old. One subject with no hearing in one ear and a mixed hearing loss in the other ear was used for the second portion. She was 56 years of age. Neither subject appeared to experience any difficulty with the test situation.

Procedure. Both subjects were given practice in listening to PB words selected from list 1 of CID auditory test W-22. Speech reception thresholds were measured following the procedure of Chaiklin and Ventry.[95] Speech reception thresholds measured at the poorer ear were obtained with no masking noise in the better ear, so that the responses were to words which had cross-lateralized from the poorer ear to the better ear.

After the practice sessions a brief rest period was provided and speech discrimination scores were obtained for both ears at sensation levels of 0, 10, 20 and 30 decibels above the speech reception thresholds for both the better and the poorer ear. In the case of the poorer ear the stimuli cross-lateralized and were heard by the better ear. No discrimination score was obtained at 30 decibels sensation level for the poorer ear on the subject with a mixed hearing loss since this level exceeded the maximum output of the Allison 22 Audiometer.

Collecting the Data. Subjects were seated at a desk during discrimination testing and wrote their responses to the PB words on previously prepared forms in the precisely same manner as in Experiment III.

Treatment of the Data. Each correct word was given a value of 2%. No statistical treatment was attempted of the data obtained inasmuch as only two subjects were used. The results will be discussed in Chapter IV and the audiometric data on the two subjects used may be seen in Appendix D.

Experiment V

Experiment V was designed to determine whether there was a significant difference in discrimination scores in subjects with mixed hearing loss when the speech stimuli were presented under the following conditions:

(A) PB words presented via a standard earphone with no contralateral masking.

(B) PB words presented via a standard earphone with minimum levels of effective masking presented to the opposite ear via a standard earphone.

(C) PB words presented via an insert earphone with minimum levels of effective masking presented to the opposite ear via an insert earphone.

The masking levels used were determined by the formula for effective masking described in Chapter I. The level of effective masking used was equal to the level at which the speech materials were delivered to the test ear, minus 40 decibels (for minimal interaural attenuation) plus the air-bone gap of the masked ear.

Subjects. A group of 12 subjects with bilaterally symetrical mixed hearing loss was selected. These subjects met the following criteria: (a) a speech reception threshold not greater than 75 decibels hearing threshold level in the poorer ear; (b) an average threshold for bone-conducted pure tones at frequencies 500, 1000 and 2000 Hertz of not less than 25 decibels hearing threshold level; (c) an air-bone gap for at least two frequencies of not less than 25 decibels. In addition, each subject had an otological examination and was diagnosed as being without ear disease at the time of testing. Five of the subjects were male and seven female. Their ages ranged from 33 to 74 with a mean age of 49.8 years.

Since all subjects had bilateral mixed losses, each ear was considered a separate entity, thus the data from 24 cases were collected in Experiment V.

Procedure. Before testing for purposes of data collecting, the subjects were given a practice list of PB words selected from CID auditory test W-22 list 1, presented first to one and then to the other ear via standard earphones. Discrimination for speech was then measured under conditions A, B and C described above.

All discrimination testing was done 30 decibels above the speech reception threshold for each condition. In order to minimize any order effects, the 12 subjects were divided into three groups of four each and were tested in the following order:

Group 1. A B C
Group 2. B C A
Group 3. C A B

Collecting the Data. Scoring was accomplished by having the subjects write their responses to the PB words as was described in Experiment III.

Treatment of the Data. To determine the amount by which a discrimination score obtained under condition A would have to be lowered in order to be significantly poorer, the test for significance of difference by proportions as described by Natrella[96] was utilized (see Appendix C).

Cases were grouped together whose discrimination test results fell into the following categories:

$A = B = C$

$A > B, \quad A = C$
$A > B, \quad B = C$
$A > B, \quad C > B, \quad A > C$

SUMMARY

Five separate experiments were carried out in the present study. The first was to determine a zero reference level for insert earphones; the second to determine zero decibels of effective masking for speech through standard and insert earphones; the third to compare speech discrimination through standard and insert earphones; the fourth to observe the effects of cross-lateralization on speech discrimination scores; and the fifth to compare speech discrimination scores when the stimuli are delivered through standard earphones with no contralateral masking, when the speech stimuli are delivered through standard earphones with contralateral masking delivered through standard earphones, and when speech stimuli and contralateral masking are both delivered through insert earphones, in cases of mixed hearing loss.

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CHAPTER IV

RESULTS

Experiment I

The first experiment was designed to compare the variance of speech reception thresholds of normal subjects as determined through standard audiometer earphones and insert earphones. Table 2 presents the results of this investigation.

TABLE 2

SPEECH RECEPTION THRESHOLDS OF NORMAL SUBJECTS AS OBTAINED THROUGH STANDARD AUDIOMETER EARPHONES AND INSERT EARPHONES (N=12)

Number of Subjects	Standard Phone		Insert Phone		Test of Significance	
	Mean	Variance	Mean	Variance	t Value	.05*
12	10.5	16.79	9.2	14.90	.4873	2.228

*Theoretical value for t at the .05 level of confidence.

No significant difference was found (at the .05 level of confidence between the variances of speech reception thresholds obtained through standard and insert earphones.

Experiment II

The second experiment was designed to determine the hearing level of white noise on an Allison 22 Audiometer that would be equal to 20 decibels of effective masking for speech through standard audiometer earphones and insert earphones. The results of this portion of the present study are seen in Table 3.

TABLE 3

HEARING LEVEL OF WHITE NOISE IN DECIBELS ON AN ALLISON 22 AUDIOMETER WHICH IS EQUAL TO TWENTY DECIBELS OF EFFECTIVE MASKING FOR STANDARD AUDIOMETER EARPHONE AND INSERT EARPHONES. (N=12)

Number of Subjects	Standard Phone		Insert Phone		Test of Significance	
	Mean	Variance	Mean	Variance	t Value	.05*
12	44.83	8.70	46.00	3.27	1.61	2.228

*Theoretical value for t at the .05 level of confidence.

No significant difference was found (at the .05 level of confidence) between the variances of measurements of 20 decibels of effective masking for speech obtained through standard and insert earphones.

Experiment III

This experiment was designed to determine whether discrimination scores obtained on PB word lists were the same for standard audiometer earphones as they were for insert earphones. Table 4 shows the results of this study.

TABLE 4

DISCRIMINATION SCORES OBTAINED ON SUBJECTS WITH BILATERALLY SYSMETRICAL SENSORI-NEURAL HEARING LOSSES THROUGH STANDARD AUDIOMETER EARPHONES AND INSERT EARPHONES
(N=12)

Number of Subjects	Standard Phone Mean	Insert Phone Mean	Test of Significance <u>t</u> Value	.05*
20	75.1%	75.2%	.08	2.093

*Theoretical value for t at the .05 level of confidence.

No significant differences were found (at the .05 level of confidence) between speech discrimination scores obtained in standard and insert earphones.

Experiment IV

The fourth experiment was designed to measure the differences, if any, on discrimination scores obtained with PB word lists when the words were presented from the opposite (non-hearing) ear through standard earphones as compared with scores presented directly to the better ear. Table 5 shows the discrimination scores of a subject who had normal hearing in her left ear and a complete sensori-neural hearing loss in her right ear.

TABLE 5

DISCRIMINATION SCORES (IN PER CENT) OBTAINED ON A SUBJECT WITH NORMAL HEARING IN HER LEFT EAR AND NO HEARING IN HER RIGHT EAR. SENSATION LEVELS ARE IN DECIBELS WITH RESPECT TO THE SPEECH RECEPTION THRESHOLDS WHICH WAS, IN THE CASE OF THE RIGHT EAR, LATERALIZED FROM THE LEFT EAR

		Discrimination Scores (in per cent)			
	Unmasked SRT	0 SL	10 SL	20 SL	30 SL
Right Ear	58	0	0	50	80
Left Ear	12	10	60	100	100

At each sensation level the speech discrimination scores were poorer when the words were cross-lateralized from the opposite (non-hearing) ear. In this case it is not possible to determine whether the cross-lateralization took place primarily by air- or bone-conduction.

Table 6 shows the discrimination scores obtained with PB words on a subject who had a mixed hearing loss in her right ear and a total sensori-neural hearing loss in her left ear.

TABLE 6

DISCRIMINATION SCORES (IN PER CENT) OBTAINED ON A SUBJECT WITH A MIXED HEARING LOSS IN HER RIGHT EAR AND A TOTAL SENSORI-NEURAL HEARING LOSS IN HER LEFT EAR

		Discrimination Scores (in per cent)			
	Unmasked SRT	0 SL	10 SL	20 SL	30 SL
Right Ear	56	22	64	92	100
Left Ear	84	14	52	80	DNT*

*Thirty decibels sensation level was not tested in the left ear as this hearing level exceeded the maximum output of the Allison 22 Audiometer.

At each sensation level the discrimination scores were lower when the words were cross-lateralized from the opposite (non-hearing) ear. In this case it is possible to state with certainty that cross-lateralization took place by bone-conduction since the difference in decibels between the air-conduction level in the better ear and the presentation level of the PB words to the deaf ear was not sufficient for cross-lateralization to have taken place by air-conduction.

Experiment V

The fifth and final experiment in the present study was designed to determine whether, in cases of bilateral mixed hearing loss, discrimination scores for PB words were altered when the opposite ear was masked with minimum levels of effective masking (as defined in Chapter III), using a standard earphone as the output transducer. This experiment also investigated the discrimination scores obtained through an insert receiver with the same amount of masking noise delivered to the opposite ear through an insert receiver. Three conditions, therefore, existed in terms of the speech discrimination tests administered to the subjects:

(A) PB words presented via a standard earphone with no contralateral masking.

(B) PB words presented via a standard earphone with minimum levels of effective masking presented to the opposite ear via a standard earphone.

(C) PB words presented via an insert earphone with minimum levels of effective masking presented to the opposite ear via an insert earphone.

Four variations were possible in terms of differences in discrimination scores.

Variation 1. That discrimination measured through standard earphones with no contralateral masking would be the same statistically as discrimination measured through a standard earphone with the contralateral ear masked through a standard earphone (A=B), and the same as discrimination measured through an insert earphone with the contralateral ear masked through an insert earphone (A=C). The discrimination scores for the subjects who fell into this category may be seen in table 7.

TABLE 7

VARIATION 1. CASES WHERE SPEECH DISCRIMINATION SCORES IN CONDITION A=B=C. (N=8)

Subject	Ear	A	B	C	A-B	A-C
2	Left	76	74	74	2	2
4	Right	76	78	76	-2	0
4	Left	78	74	78	4	0
6	Right	90	90	90	0	0
10	Right	92	92	94	0	-2
10	Left	92	90	92	2	0
12	Right	88	88	84	0	4
12	Left	90	86	86	4	4
	Mean =	85.3	84.0	84.5	1.3	1.0

In eight cases no significant differences in speech discrimination scores occurred when discrimination was measured through a standard earphone with no contralateral masking (A), through a standard earphone with contralateral masking delivered through a standard earphone (B), or through an insert earphone with contralateral masking delivered through an insert earphone (C).

Variation 2. The second possible variation was that A would be equal to C but greater than B. Table 8 identifies the cases in which this occurred.

TABLE 8

VARIATION 2. CASES WHERE SPEECH DISCRIMINATION SCORES IN CONDITION A=C, A> B. (N=9)

Subject	Ear	A	B	C	A-B	A-C
1	Right	94	70	92	24	2
1	Left	96	92	94	24	2
3	Right	98	68	96	30	2
3	Left	98	88	96	10	2
5	Right	94	76	88	18	6
5	Left	92	78	90	14	2
6	Left	92	74	84	18	10
8	Left	90	70	92	20	-2
9	Right	82	64	72	18	8
	Mean =	92.9	73.3	89.3	19.6	3.6

In nine cases speech discrimination scores were significantly higher when measured through a standard earphone with no contralateral masking (A) than with a standard earphone with contralateral masking delivered through a standard earphone (B). Scores were statistically the same when PB words were delivered through a standard earphone with no contralateral masking as they were when delivered through an insert earphone with contralateral masking delivered through an insert earphone (C).

Variation 3. The third possible variation in speech discrimination scores was that A would be greater than B, but B would be equal to C. See Table 9.

TABLE 9

VARIATION 3. CASES WHERE SPEECH DISCRIMINATION SCORES IN CONDITION A > B, B=C. (N=5).

Subject	Ear	A	B	C	A-B	B-C
2	Right	76	62	60	14	2
8	Right	98	68	70	30	-2
9	Left	82	70	74	12	-4
11	Right	96	78	76	18	2
11	Left	88	58	60	28	-2
	Mean =	88.0	67.2	68.0	20.4	-1.2

In five cases speech discrimination scores were significantly higher with no contralateral masking (A) than with masking through a standard earphone (B). In these cases the discrimination scores were the same for both a standard earphone with contralateral masking through a standard earphone (B) and an insert earphone with contralateral masking through an insert earphone (C).

Variation 4. The last possible variation in speech discrimination scores was that A would be greater than B, and greater than C, but C would be greater than B. These results can be seen in Table 10.

TABLE 10

VARIATION 4. CASES WHERE SPEECH DISCRIMINATION SCORES IN CONDITION A > B, A > C, C > B. (N=2).

Subject	Ear	A	B	C	A-B	C-B
7	Right	96	48	80	18	10
7	Left	94	60	82	34	22
	Mean =	95.0	54.0	81.0	26.0	16.0

In two cases the speech discrimination scores were higher without contralateral masking (A) than with contralateral masking whether the masking was delivered through a standard (B) or an insert (C) earphone. Speech discrimination scores were significantly higher when measured through an insert receiver with the masking noise delivered through an insert receiver (C) than with a standard receiver with the masking noise delivered through a standard receiver (B).

SUMMARY

The results presented in this chapter indicate that there was no difference in the variance of speech reception thresholds or measurements of effective masking as presented through standard and insert earphones. There was no difference in discrimination scores when the words were presented through either a standard or insert earphone.

PB words presented from the opposite (non-hearing) ear of a unilaterally deaf subject apparently suffered some distortion in cross-lateralization. Evidence for this fact is that discrimination scores obtained in this fashion were lower than those obtained at identical sensation levels with the words presented directly to the test ear. Results were similar for a subject with one deaf ear and a mixed hearing loss in the other ear. This indicates that cross-lateralization for speech stimuli can take place by bone-conduction.

Eight cases with mixed hearing loss showed no effect on their PB scores when the opposite ear was masked through a standard earphone, and when the speech and masking were both presented through an insert earphone. Nine cases showed a significant decrease in speech discrimination scores when the opposite ear was masked through a standard earphone but no significant change in discrimination when speech and masking were presented through insert earphones. Five cases with mixed hearing loss showed the same amount of increased discrimination loss caused by the introduction of contralateral masking through a standard or insert earphone. Two cases of mixed hearing loss showed a significant decrease in discrimination scores produced by contralateral masking through an insert earphone and a further significant decrease when the masking was presented via a standard earphone.

CHAPTER V

SUMMARY, CONCLUSIONS, DISCUSSION, RECOMMENDATIONS

Summary

The purpose of this study was to determine whether, in some cases of mixed hearing loss, speech discrimination scores are altered by participation in the test by the opposite (non-test) ear. The basic hypothesis was that since speech discrimination materials are delivered at a fairly high sensation level, the intensity at the output (air-conduction) transducer might be sufficient to generate a bone conducted signal which would be heard by the opposite ear. In such a case both ears would hear the speech materials and the scores might be higher than if the test ear alone heard the words. To be certain that the non-test ear was eliminated from the test a masking noise would have to be introduced to that ear which would be just intense enough to mask out a speech signal reaching that cochlea by bone-conduction. It would appear that a high level of noise would be needed in some cases and that, after some degree of energy loss, the masking noise would reach the test cochlea by cross-lateralization in the same way that the speech materials reached the masked cochlea. This would result in a confounding of results, in this latter case by lowering the PB scores, and in the former case by raising them.

If no masking in a speech discrimination test produced one kind of error of measurement and minimum masking resulted in a different error then it would seem that at least one difficulty lay in the relatively small amount of interaural attenuation. An increase in interaural attenuation would, if sufficient, mitigate the difficulty. Since insert earphones have been demonstrated repeatedly to have greater interaural attenuation than standard phones, the use of insert phones was thought to be a possible solution. A number of authors have suggested insert phones for masking, but there has been no evaluation of them for speech discrimination testing.

Before insert earphones could be used either for masking or speech audiometry, several facts had to be learned about them. First of all a zero reference for speech had to be determined on normal subjects. After this was done, zero decibels of effective masking had to be determined and the results compared to those obtained through standard audiometer earphones. The determination of normal threshold for speech in standard audiometer earphones has been determined and can be measured on an artificial ear. No such standardization exists either for normal threshold for speech through insert phones or zero decibels of effective masking through either insert or standard earphones. It must be emphasized, therefore, that results on these measures obtained in the present study cannot be generalized to other audiometers, other insert phones or other noise generators.

Once a zero reference level for speech and effective masking was determined, it was then necessary to learn whether speech discrimination scores obtained through insert earphones were the same as those obtained through standard audiometer earphones. Tests of discrimination using PB words on 20 subjects with sensori-neural hearing loss indicated that at 30 decibels sensation level the scores were not significantly different for these two types of transducers. Practice sessions and random presentation were employed to minimize learning and order effects.

Kodman[97] found that speech materials presented through earphones from one ear suffer some frequency distortion in reaching the other ear. This he attributed to a greater energy loss for high frequency sounds during cross-lateralization. In order to observe this phenomenon, two subjects were tested. One had normal hearing in one ear and a total sensori-neural loss in the other. In this case by testing at sensation levels of 0, 10, 20 and 30 decibels it could be seen that the discrimination scores obtained from the poorer ear under standard earphones as a shadow of the better ear were poorer than those obtained directly from the better ear at the same sensation levels. Another subject having a mixed hearing loss in one ear and a total sensori-neural loss in the other ear was tested in a similar fashion. Again the discrimination scores were poorer from the side with the deaf ear, illustrating the effects on speech materials during cross-lateralization.

This case also illustrates that cross-lateralization for speech materials can, and did take place by bone-conduction, since the difference in decibels between the speech reception threshold of the ear with the mixed loss and the presentation of the speech materials to the deaf ear was not sufficient for the energy to have reached the better ear via air-conduction.

Conclusions

The data from experiments I and II demonstrated that speech reception thresholds and effective masking can be determined psychoacoustically on insert phones as well as standard earphones and gave a zero reference level for the present research. Experiment III demonstrated that PB word scores were the same for standard audiometer earphones and insert earphones. Therefore insert earphones, after appropriate calibration procedures have been carried out, may be substituted for standard audiometer earphones for use in testing speech reception thresholds, discrimination for PB words, and for masking of speech stimuli. No generalization may be made from these results to other speech materials or pure tone stimuli until these areas have been investigated.

Experiment IV demonstrated that PB words, as supralimenal stimuli, may lateralize from one ear to another if they are presented at an intensity high enough to stimulate the contralateral cochlea by bone-conduction. There is apparently some distortion of the speech signal as it crosses the skull from one ear to another.

In the situation where PB words are presented to subjects with bilateral mixed loss, the signal is not only heard in one ear as a slightly distorted monotic signal, but as a dichotic signal. This may indicate that the hypothesis presented in Chapter I was erroneous. This stated that in the case of a cross-lateralized speech signal the subject would experience a loud distorted signal in one ear (as presented by air-conduction to that ear) in addition to a weak undistorted signal in the opposite ear (as lateralized by bone-conduction). What was thought to be a replication of the Bocca effect,[98] therefore, may not have been truly so.

Experiment V illustrated that the results on speech discrimination tests in cases of mixed hearing loss may indeed be inaccurate unless appropriate masking procedures are used. The contribution of the contralateral ear during a speech discrimination test may serve to obscure a poor discrimination score in the test ear. The discrimination score with the speech presented through one insert phone and effective masking through the other insert phone may be a criterion inasmuch as this type of receiver lessens the likelihood of opposite ear participation in a discrimination test.

In some cases speech discrimination scores were statistically the same in conditions of PB words through standard earphones with no contralateral masking, speech through standard earphones with contralateral masking through standard earphones and speech through insert earphones with contralateral masking through insert earphones. In these cases, it would appear, that the ear opposite to the test ear was not taking part in the test and thereby increasing the scores. This may have been due to an increased amount of interaural attenuation for these subjects.

In other cases of mixed hearing loss the speech signal was statistically higher through standard earphones without masking than with contralateral masking. This would seem to indicate that the speech discrimination was being augmented by cues presented to the opposite ear. This could have improved the discrimination either because the non-test ear had better discrimination than the test ear or because the speech signal became dichotic.

In still other cases the speech discrimination scores were the same without contralateral masking as they were when the speech stimuli and masking were delivered through insert phones. In these cases discrimination was significantly poorer when the speech signal and masking were presented via standard earphones. In these cases, it would seem that masking through a standard receiver produced overmasking, but presenting both the speech and masking through insert receivers isolated the test ear from the masked ear sufficiently so that a weaker speech signal reached the masked ear and the masking noise was more efficiently isolated to the masked ear.

Finally, speech discrimination scores were highest with no contralateral masking, lowest when masking was presented through a standard earphone, and at some point in between when both the speech and masking were presented through insert phones. The reason for this effect is obviously that minimum effective masking through standard earphones is sufficient to produce overmasking and a lowering of discrimination scores in some cases.

The additional interaural attenuation provided by insert phones seems to have eliminated the overmasking phenomenon, as well as effectively eliminating the non-test ear.

Discussion

In light of the somewhat unpredictable results obtained in Experiments IV and V, it would seem that a discussion of these findings is warranted.

The purpose of Experiment IV was to test the hypothesis that there is no significant difference between speech discrimination scores obtained at the better ear of unilaterally deafened subjects, and similar scores obtained when the speech discrimination materials had cross-lateralized from the poorer ear. Examination of the data in Tables 5 and 6 shows that cross-lateralized speech stimuli give rise to discrimination scores which are significantly poorer than similar scores obtained when the transducer delivering the speech stimuli is placed at the test ear. The articulation functions obtained on the two subjects in Experiment IV were typical on the basis of visual inspection. This does not at all mean that they should be disregarded but rather that it is not known at this time where on the continuum of a large sample they lie. It is conceivable that these data could be important when more sampling is done in this area. An explanation of these findings would be that the acoustic spectrum of speech is altered in the course of cross-lateralization. Further research is indicated to explain this effect. Results of this experiment are only indirectly related to Experiment V since it was anticipated that in Experiment V speech materials were received dichotically and in Experiment IV monotically.

The purposes of Experiment V were twofold. The first purpose was an attempt to investigate the effect cross-lateralized bone-conducted speech stimuli has on speech discrimination data in subjects with mixed hearing loss. To do this, measurements were made at both ears of subjects with bilaterally symetrical mixed hearing loss. The question could be raised as to whether using the two ears as a source of testing and data collection might not introduce an uncontrolled variable into the design. Each ear was considered a separate case because it was felt that collecting data on just one ear of a subject would not provide knowledge of the discrimination of the untested ear.

The data presented in Tables 7, 8, 9 and 10 exhibit heterogeneity. For example, in terms of the possible variations, eight subjects (1, 3, 4, 5, 7, 10, 11 and 12) showed both ears falling into the same categories and four subjects (2, 6, 8 and 9) showed the results of masking the right ear to cause an effect (or lack of effect) on the left ear, while masking the left ear caused a different effect on the right ear. This indicates that there are unpredictable effects due to the variables associated with the phenomenon of masking for speech discrimination in mixed hearing loss. These unpredictable effects occur not only from subject to subject, but from one ear to the other for the same subject. These data clearly indicate the erroneous conclusion that would have resulted from studying the effects of masking on speech discrimination in only one ear on subjects whose unmasked speech discrimination scores appeared to be equal for both ears. In some cases one ear was poorer than the other for masked speech discrimination. This was the case in four out of 12 subjects tested.

From an analysis of the data, it can be seen that cues produced by cross-lateralized speech signals may have an effect on speech discrimination scores in a significant number of cases but not necessarily in a systematic or predictable fashion. For example, three subjects showed no effect on their speech discrimination scores for either ear whether or not masking was used. A careful examination of the audiometric data for these subjects (see Appendix D), based on differences between the hearing level at which the PB words were presented to one ear and the bone-conduction thresholds of the opposite ear, fails to explain this lack of change in scores. It can only be assumed, therefore, that either the interaural attenuation of these subjects, which is doubtlessly produced by a number of individual variations such as head size and shape, hair and scalp was greater than in some other cases; or that the sensation level required for these subjects to achieve binaural fusion was higher than for some other subjects.

In two subjects, the speech discrimination scores for one ear were unaltered when contralateral masking was used. For subject 2, masking through either standard or insert phones served to indicate that the right ear was, in fact, poorer even though it appeared to be the same for speech discrimination as the left ear. Over masking did not occur when the same noise levels were delivered via insert phones. Careful review of the audiometric data of this subject fails to reveal the explanation for the significant effect of masking upon one ear with no apparent effect upon the other ear.

Three cases (subjects 1, 3 and 5) appeared to show that over masking took place for both ears when masking was introduced through standard earphones but over masking did not take place when the noise was delivered through an insert earphone. Three subjects (6, 8 and 9) showed this effect for one ear but not for the other. Data for subjects 8 and 9 illustrated that for one ear the discrimination was in fact significantly better than the other and that masking was needed to indicate this fact, although over masking with standard earphones did not take place. One subject (11) illustrated this effect in both ears. Data for one subject (7) showed that (1) over masking took place when standard phones were used but not when insert phones were used, and (2) that masking was indeed required to eliminate the non-test ear from participation in one discrimination task. Such an effect, for this subject, could have been predicted on the basis of her relatively large air-bone gap for the low frequencies.

The second purpose of the present research was to establish methods of eliminating any contralateral participation in speech discrimination tests. The use of insert earphones appears, based on the preliminary data presented, to provide the possibility of using the needed masking while lessening the possibility of over masking. This is probably due to the provision of a minimum of 20 decibels more interaural attenuation through insert earphones over standard earphones.

The variety of results obtained in Experiment V can only partially be explained in terms of variables studied in this research.

Future research on this subject should isolate such variables as age, sex, locus of pathology, etiology of hearing loss, duration of loss and data on tests specifically designed to test for binaural fusion as well as individual interaural attenuation.

It is apparent from the results of the present study that precautions must be taken against the contribution of the contralateral ear to speech discrimination tests in cases of mixed hearing loss. The use of insert receivers appears to satisfy this need, at least when PB words are the test materials.

In Experiment V the same amount of masking was used when both insert and standard phones were used for the masking transducer. The formula used was PBHL - IA + ABG = EM (the hearing level of the PB words minus the interaural attenuation which was set at 40 decibels as a conservatively low figure plus the largest air-bone gap seen on the audiogram).

There is ample evidence in the literature, as well as the evidence which may be inferred from the present research about the additional interaural attenuation provided by insert phones. This being the case, 60 decibels may be substituted for 40 decibels as minimum interaural attenuation when insert phones are to be used. This would lower the level of the noise in a subject's ear by 20 decibels decreasing even further the likelihood of over masking resulting from high noise levels. It would also decrease the discomfort experienced by some subjects when they are forced to listen to loud and prolonged noise. The reason that 60 decibels was not used as the figure for interaural attenuation during Experiment V is that a lower noise level could have provided a different explanation for the higher scores achieved by some subjects through insert rather than standard phones. This lower level of required noise makes the argument for insert phones even more compelling as a clinical tool.

Recommendations

Findings of the present research seem to provide support for the following clinical and research recommendations:

1. Decision to Mask. Masking is needed whenever the presentation level of speech

materials minus the interaural attenuation for the low frequency components (40 decibels) is above the best bone-conduction threshold of the opposite ear.

2. Calibration. In order to avoid confusion, great care must be given to calibration in terms of effective masking for speech. This calibration must be carried out for each audiometer until some standard is set for electro-acoustic calibration on an artificial ear.

3. Amount of Masking. The formula PBHL - IA + ABG developed in this research is the only one known to the author which satisfies the need that the cochlea of the non-test ear will receive just enough noise to effectively mask out a signal reaching it.

4. Choice of Masking Transducers. Insert receivers should be used for both the speech stimuli and masking stimuli when testing speech discrimination in cases of mixed hearing loss whenever the danger of over masking presents itself. This research did not study the cross-lateralization effects on other types of hearing impairments.

5. Future Research. Research should be carried out using speech materials other than PB words. Insert receivers other than the Beyer phones should be evaluated in terms of their effect on cross-lateralization as a variable in the measurement of speech discrimination. Findings of such studies should result in recommendations to manufacturers of speech audiometers concerning inclusion of matched pairs of insert earphones as accessory output transducers for use in discrimination testing of selected cases where cross-lateralization is suspected.

Normative data of effective masking for speech should be obtained using a large number of subjects with normal hearing. Such data would serve as a guide to manufacturers who wish to make available speech audiometers with calibrated masking generators. Such normative data would also facilitate calibration, in the field, of the masking source of speech audiometers.

Insert earphones should be evaluated in the context of supraliminal hearing tests other than speech discrimination to reduce the effects of cross-lateralization of test stimuli.

Further research along the lines suggested by the present project should be undertaken with an attempt at revealing the cause for some of the variables appearing in the present research. Placement of subjects with mixed hearing loss into groups displaying homogeneity of such factors as age air-bone gap, middle ear conditions, interaural attenuation and binaural fusion should provide some explanation for the variables encountered in Experiment V.

Additional research should be carried out to describe the effects of cross-lateralization of speech discrimination materials on unilaterally deafened subjects so that some knowledge of the loss of fidelity produced by cross-lateralization can be obtained.

Whereas the present research has been concerned with evaluation of changes in the magnitude of speech discrimination scores as a result of cross-lateralization, future research should describe the qualitative as well as the quantitative effects of cross-lateralized speech stimuli with subjects with various kinds of hearing loss.

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APPENDICES

APPENDIX A

Maximum Allowable Sound Pressure Levels (SPL's) in Decibels Re 0.0002 Dynes/CM^2 Required for Testing the Air-Conduction Thresholds of Normal Hearing Subjects on the ISO-1964 Scale and Comparison to Sound Pressure Levels in the Test Room Used in the Experiments in the Present Study.

Frequency	125	250	500	1000	2000	4000	8000
1. ASA-1951 Standard	40	40	40	40	47	57	67
2. ISO-1964 Standard	9	15	14	10	8.5	6	11.5
3. Max. SPL for testing on ISO-1964 Scale (1-2)	31	25	26	30	38.5	51	55.5
4. SPL's in Test Room	38	27	14	12	12	13	14
5. Amount by which test room exceeds minimum requirements. (3-4)	-7	-2	12	18	26.5	38	41.5

APPENDIX B

The twelve subjects with normal hearing used to determine calibration for speech reception thresholds of insert receivers. The unit of measurement was the decibel.

Subject	Ear	Sex	Age	SRT-Standard Phone	SRT-Insert Phone
1	Right	Male	24	-6	-4
2	Right	Female	20	8	6
3	Left	Female	20	6	2
4	Left	Female	21	-2	-4
5	Right	Female	21	-4	-4
6	Right	Female	20	0	0
7	Left	Female	18	-2	-6
8	Left	Female	20	4	4
9	Right	Female	21	2	2
10	Left	Female	20	0	0
11	Left	Male	19	-2	-4
12	Right	Female	21	2	0

The twelve subjects with normal hearing used to determine calibration for twenty decibels of effective masking (EM) for speech using standard and insert earphones as output transducers. The unit of measurement was the decibel.

Subject	Ear	Sex	Age	EM-Standard Phone	EM-Insert Phone
1	Right	Male	24	50	48
2	Right	Female	20	42	44
3	Left	Female	20	42	48
4	Left	Female	21	44	48
5	Right	Female	21	48	44
6	Right	Female	20	40	44
7	Left	Female	18	44	48
8	Left	Female	20	48	44
9	Right	Female	21	44	46
10	Left	Female	20	46	46
11	Left	Male	19	44	46
12	Right	Female	21	46	46

The twenty subjects with bilaterally symetrical sensori-neural hearing loss used to determine discrimination scores on PB word lists using standard and insert earphones as output transducers. Speech Reception Thresholds (SRT's) were measured in decibels and Discrimination scores in per cent.

			Standard Phone		Insert Phone	
Subject	Sex	Age	SRT	Discrim.	SRT	Discrim.
1	Female	64	30	88	30	86
2	Male	72	60	62	62	72
3	Male	35	34	88	38	90
4	Male	70	60	78	62	76
5	Female	42	30	90	26	88
6	Male	58	44	66	40	58
7	Female	65	38	88	38	88
8	Female	59	28	82	30	88
9	Male	60	36	88	34	90
10	Male	48	56	38	54	42
11	Male	28	26	86	24	78
12	Female	37	50	54	54	66
13	Female	41	32	80	28	86
14	Female	55	60	46	58	44
15	Male	60	30	76	26	68
16	Female	61	30	82	30	80
17	Female	42	30	86	34	88
18	Female	29	42	88	40	86
19	Male	61	50	76	54	72
20	Female	76	54	60	58	58

The twelve subjects with bilaterally symetrical mixed hearing loss used to compare discrimination scores on PB word lists using, (A) a standard phone for speech with no contralateral masking, (B) a standard phone for speech with contralateral masking through a standard phone and (C) an insert phone for speech with an insert phone for contralateral masking. All numbers are per cent correct.

Group 1. Test Order: A, B, C.

Subject	Ear	Standard Phone Unmasked	Standard Phone Masked	Insert Phone Masked
1	Right	94	70	92
	Left	96	72	94
2	Right	76	62	60
	Left	76	74	74
3	Right	98	68	96
	Left	98	88	96
4	Right	76	78	76
	Left	78	74	78

Group 2. Test Order: B, C, A.

Subject	Ear	Standard Phone Unmasked	Standard Phone Masked	Insert Phone Masked
5	Right	94	76	88
	Left	92	78	90
6	Right	90	90	90
	Left	92	74	84
7	Right	96	48	80
	Left	94	60	82
8	Right	98	68	70
	Left	90	70	92

Group 3. Test Order: C, A, B.

Subject	Ear	Standard Phone Unmasked	Standard Phone Masked	Insert Phone Masked
9	Right	82	64	72
	Left	82	70	74
10	Right	92	92	94
	Left	92	90	92
11	Right	96	78	76
	Left	88	58	68
12	Right	88	88	84
	Left	90	86	86

APPENDIX C

Percentages Which Must be Exceeded for Speech Discrimination Scores to be Significantly Poorer than Initial Measurements.

Criterion Discrimination Score	.05 Confidence Level	Differences
60	48	-12
62	50	-12
64	52	-12
66	54	-12
68	56	-12
70	57	-13
72	59	-13
74	62	-12
76	64	-12
78	67	-11
80	69	-11
82	71	-11
84	72	-12
86	75	-11
88	77	-11
90	79	-11
92	82	-10
94	85	- 9
96	88	- 8
98	94	- 4

APPENDIX D

Audiometric Data on the Two Subjects with a Total Loss of Hearing In One Ear. These Subjects Were Used to Observe the Effect of Cross-Lateralization on Discrimination for Speech Using PB Words as the Speech Stimuli.

Subj	Sex	Age	Ear	Mode	250	500	1000	2000	3000	4000	8000
1	F	49	R	AC	55	60	60	60	65	65	65
			R*	AC	NR	NR	NR	NR	NR	NR	NR
			R	BC	10	20	20	15	--	15	--
			R*	BC	50	NR	NR	NR	--	NR	--
			L	AC	15	20	20	10	10	15	20
			L	BC	10	15	20	15	--	15	--
2	F	56	R	AC	55	65	50	45	75	85	85
			R	BC	20	20	15	30	--	35	--
			L	AC	85	90	80	80	95	105	NR
			L*	AC	NR	NR	NR	NR	NR	NR	NR
			L	BC	20	20	15	30	--	35	--
			L*	BC	NR	NR	NR	NR	NR	NR	NR

Legend:

Units numbered 250 through 8000 are frequency in Hertz.

Units within the audiometric data are decibels re normal hearing on the ISO-1964 scale.

R - right ear.
L - left ear.
AC - Air-Conduction.
BC - Bone-Conduction.
NR - No patient response at maximum output of the audiometer.
-- - Frequency not tested.
* - Opposite ear masked.

Audiometric Data on the twelve subjects with bilateral mixed hearing losses used to compare discrimination scores through standard and insert earphones with and without masking. See the legend in the previous table for an explanation of abreviations.

Subj	Initials	Sex	Age	Ear	Mode	250	500	1000	2000	3000	4000	8000
1	RG	F	38	R	AC	60	50	40	35	35	50	40
				R	BC	15	15	25	35	--	30	--
				L	AC	50	55	40	40	40	55	50
				L	BC	10	20	25	30	--	35	--
2	GN	F	74	R	AC	65	50	55	65	70	75	NR
				R	BC	30	25	35	45	--	60	--
				L	AC	60	60	55	55	75	80	NR
				L	BC	25	25	25	40	--	65	--
3	WD	M	49	R	AC	45	55	40	35	50	45	65
				R	BC	30	20	30	30	--	20	--
				L	AC	40	50	35	5	25	35	55
				L	BC	30	25	25	35	--	20	--
4	WP	M	35	R	AC	65	70	65	75	80	95	NR
				R	BC	25	25	35	50	--	NR	--
				L	AC	65	65	75	70	85	100	NR
				L	BC	30	25	30	55	--	NR	--

Audiometric Data (cont'd.)

Subj	Initials	Sex	Age	Ear	Mode	250	500	1000	2000	3000	4000	8000
5	RC	F	44	R	AC	35	50	55	55	70	75	55
				R	BC	15	15	30	50	--	55	--
				L	AC	40	50	50	50	50	65	70
				L	BC	15	25	30	50	--	55	--
6	JD	M	66	R	AC	55	45	40	35	50	65	60
				R	BC	15	15	20	45	--	60	--
				L	AC	40	40	50	55	80	100	NR
				L	BC	20	15	15	45	--	55	--
7	MC	F	33	R	AC	65	60	70	80	80	95	NR
				R	BC	10	15	35	40	--	NR	--
				L	AC	65	65	75	75	85	90	NR
				L	BC	15	15	30	40	--	60	--
8	RH	M	51	R	AC	55	45	55	55	65	70	90
				R	BC	20	20	35	40	--	70	--
				L	AC	50	50	60	65	70	85	NR
				L	BC	15	20	25	35	--	70	--

Audiometric Data (cont'd.)

Subj	Initials	Sex	Age	Ear	Mode	250	500	1000	2000	3000	4000	8000
9	AW	F	53	R	AC	65	60	55	60	70	70	NR
				R	BC	20	25	30	40	--	40	--
				L	AC	55	55	60	55	60	65	80
				L	BC	15	15	25	30	--	35	--
10	NW	F	73	R	AC	70	75	70	70	65	55	NR
				R	BC	35	30	30	35	--	20	--
				L	AC	70	70	60	60	60	60	90
				L	BC	30	30	30	30	--	25	--
11	GH	M	48	R	AC	55	65	65	45	70	45	60
				R	BC	15	20	20	35	--	45	--
				L	AC	45	45	45	45	70	80	85
				L	BC	15	15	15	30	--	45	--
12	MC	F	33	R	AC	50	50	55	45	40	45	30
				R	BC	10	10	20	35	--	30	--
				L	AC	45	50	50	40	35	45	25
				L	BC	15	10	20	35	--	35	--

APPENDIX E

CID Auditory Test W-22, List 1A. Different Permutations of This List Were Used During Practice Sessions Only For the Speech Discrimination Tasks in the Present Study.

1. An
2. yard
3. cave
4. us
5. day
6. toe
7. felt
8. stove
9. hunt
10. ran
11. knees
12. not
13. mew
14. low
15. owl
16. it
17. she
18. high
19. there
20. earn
21. twins
22. could
23. what
24. bathe
25. ace
26. you
27. as
28. wet
29. chew
30. see
31. deaf
32. them
33. give
34. true
35. isle
36. or
37. law
38. me
39. none
40. jam
41. poor
42. him
43. skin
44. east
45. thing
46. dad
47. up
48. bells
49. wire
50. ache

CID Auditory Test W-22, List 2A. Different Permutations of This List Were Used for Testing Speech Discrimination in the Present Study.

1. yore
2. bin
3. way
4. chest
5. then
6. ease
7. smart
8. gave
9. pew
10. ice
11. odd
12. knee
13. move
14. new
15. jaw
16. one
17. hit
18. send
19. else
20. tare
21. does
22. do
23. cap
24. with
25. air
26. and
27. young
28. cars
29. tree
30. dumb
31. that
32. die
33. show
34. hurt
35. own
36. key
37. oak
38. new
39. live
40. off
41. ill
42. rooms
43. ham
44. star
45. eat
46. thin
47. flat
48. well
49. by
50. ail

CID Auditory Test W-22, List 3A. Different Permutations of This List Were Used for Testing Speech Discrimination in the Present Study.

1. bill
2. add
3. west
4. cute
5. start
6. ears
7. tan
8. nest
9. say
10. is
11. out
12. lie
13. three
14. oil
15. king
16. pie
17. he
18. smooth
19. farm
20. this
21. done
22. use
23. camp
24. wool
25. are
26. aim
27. when
28. book
29. tie
30. do
31. hand
32. end
33. shove
34. have
35. owes
36. jar
37. no
38. may
39. knit
40. on
41. if
42. raw
43. glove
44. ten
45. dull
46. though
47. chair
48. we
49. ate
50. year

CID Auditory Test W-22, List 4A. Different Permutations of This List Were Used for Testing Speech Discrimination in the Present Study.

1. all
2. wood
3. at
4. where
5. chin
6. they
7. dolls
8. so
9. nuts
10. ought
11. in
12. net
13. my
14. leave
15. of
16. hang
17. save
18. ear
19. tea
20. cook
21. tin
22. bread
23. why
24. arm
25. yet
26. darn
27. art
28. will
29. dust
30. toy
31. aid
32. than
33. eyes
34. shoe
35. his
36. our
37. men
38. near
39. few
40. jump
41. pale
42. go
43. stiff
44. can
45. through
46. clothes
47. who
48. bee
49. yes
50. am

APPENDIX F

Sample Scoring Sheet Used on Subjects in Experiments III, IV and V in Recording Their Responses to PB Word Lists.

1 ______________________

2 ______________________

3 ______________________

4 ______________________

5 ______________________

6 ______________________

7 ______________________

8 ______________________

9 ______________________

10 ______________________

11 ______________________

12 ______________________

13 ______________________

14 ______________________

15 ______________________

16 ______________________

17 ______________________

18 ______________________

19 ______________________

20 ______________________

21 ______________________

22 ______________________

23 ______________________

24 ______________________

25 ______________________

26 ______________________

27 ______________________

28 ______________________

29 ______________________

30 ______________________

31 ______________________

32 ______________________

33 ______________________

34 ______________________

35 ______________________

36 ______________________

37 ______________________

38 ______________________

39 ______________________

40 ______________________

41 ______________________

42 ______________________

43 ______________________

44 ______________________

45 ______________________

46 ______________________

47 ______________________

48 ______________________

49 ______________________

50 ______________________

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